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**SKIN TEMPERATURE RESPONSES TO SIMULATED
THERMONUCLEAR FLASH**

*Thermal effects
of nuclear flash
simulated*
2-1-61
**WILLIAM C. KAUFMAN, CAPT, USAF
A. G. SWAN, MAJOR, USAF**

**BIOMEDICAL LABORATORY
AEROSPACE MEDICAL LABORATORY**

AND

**H. T. DAVIS, 1/LT, USAF
DEPUTY FOR TECHNOLOGY**

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**AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO**

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*WILLIAM C. KAUFMAN, CAPT, USAF
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SEPTEMBER 1961

*PROJECT No. 7222
TASK No. 722204*

**AERONAUTICAL SYSTEMS DIVISION
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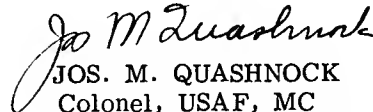
FOREWORD

The research providing data for this study was performed by Aerospace Medical Laboratory and Deputy for Technology personnel. Maj Swan and Capt Kaufman of the Biophysics Branch, Biomedical Laboratory conducted their research under Project 7222, "Biophysics of Flight"; Task 72204, "Human Thermal Stress in Extended Environment." Lt Davis, Structures Branch, Flight Dynamics Laboratory, Directorate of Aeromechanics, worked in support of Task 40642, "Prediction of Thermal Radiation on Aircraft."

ABSTRACT

Skin temperatures and radiant energy were measured on a subject wearing flight clothing, sitting in a tactical aircraft exposed to thermal energy characteristic of thermonuclear weapons. Radiant energy source was 960 lamps at power levels up to 4000 kilowatts. After exposures of increasing severity, subject tolerance was attained in a 3 cal/cm² pulse of 3.7 seconds duration. This pulse charred paint on the fuselage and headrest and seared the subject's glove. Bare forehead skin temperature reached 126° F resulting in distinct pain. The data provide a basis for calculating the nearest safe distance of aircrew members to a nuclear explosion.

PUBLICATION REVIEW


JOS. M. QUASHNOCK
Colonel, USAF, MC
Chief, Biomedical Laboratory
Aerospace Medical Laboratory

PREFACE

The results of strictly applied research in a simulated tactical situation are compared with data from the open literature gathered under research laboratory conditions. Only a single series of experiments with one subject was possible, because the power source and controller were urgently needed for higher priority research projects. However, since the experiment was of a physical nature, i.e., the thermal stress was of such short duration as to preclude any physiological responses, the subject responded as an inanimate object. Under the conditions of the experiment, the final skin temperature is dependent on the mass and initial skin temperature of the subject and the duration and intensity of the thermal stress. Consequently, further experimentation can only provide data duplicating these results.

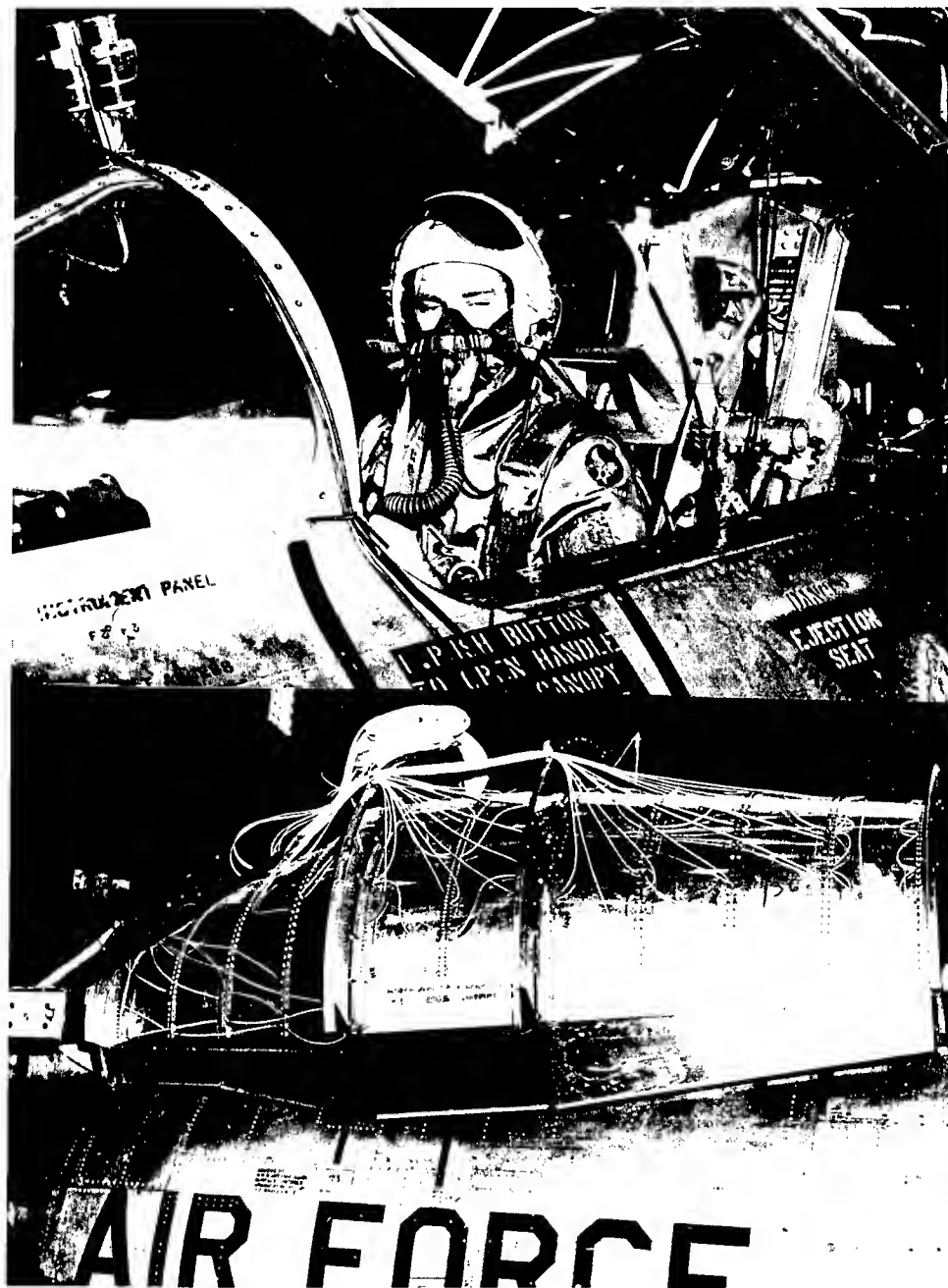


Figure 1. Subject in Fighter Cockpit. Radiometers can be seen on windscreen bow and behind headrest. Forehead thermocouple is visible. Below, a view of the airplane with hood and lamps lowered for the experiment.

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INTRODUCTION

Thermonuclear effects on a target area and its occupants have been thoroughly investigated (refs. 1, 5). However, the well-being of crewmembers in the attacking aircraft, who may also be exposed to harmful effects of the explosion, has not received equal attention. Since the accuracy of weapon delivery may be inversely related to the distance of the aircraft from the target, the nearest safe distance of the aircraft to the explosion must be determined.

The attenuation of bomb effects by weather conditions and distance has been determined (ref. 5). Heat transfer equations have enabled calculation of skin temperatures that may result from high incident radiant energy (refs. 2, 3) and the relationship of pain to skin temperatures has been explored (refs. 7, 9, 10, 11, 12). The present study was performed to assess the effects of simulated nuclear flash on the pilot and cockpit of a tactical fighter and to determine the tolerance of the operationally clothed crewmember to severe radiant energy pulses.

METHODS

The nuclear flash was simulated by 960 tungsten filament quartz lamps mounted in an hydraulically operated aluminum reflector so they were approximately 18 inches from an F-100 canopy at all points (figure 1). A 4000-kilowatt power source was suitably programmed to simulate the nuclear thermal radiation pulse (figure 2). Radiant energy was measured with eight radiometers and eight calorimeters* at the canopy surface and within the cockpit at head and hand levels.

A healthy young engineering officer served as subject. Skin temperatures were sensed by 0.010 inch O.D. copper-constantan thermocouples at knee, shoulder, face (under oxygen mask) and bare forehead. Knee and shoulder were chosen because their surfaces were perpendicular to the incident energy, the face, because the dark mask might rapidly absorb energy, and the forehead, because it was the only bare skin exposed on the operationally dressed subject. The forehead thermocouple was stretched between two pieces of adhesive tape so it was pressed into the skin slightly. Ninety percent response time of the thermocouples to a square wave of 20° F was 0.08 seconds.

RESULTS

Preliminary studies to determine the exact characteristics of the controller and energy levels obtainable were made without a subject in the cockpit. The total radiant energy for the first experiment with a human subject was 1.53 cal/cm² within the cockpit at head level. The duration of the

*Developed by US Naval Defense Laboratory, San Francisco, California.

pulse was 3 seconds. This was an energy level estimated from published data to cause little, if any, skin temperature response (ref. 8). Total radiant energy of 2.4 cal/cm^2 and pulse duration of 4 seconds in the second experiment caused bare forehead skin temperature to increase 18° F to a maximum of 119° F . In the third experiment total radiant energy was 3 cal/cm^2 and pulse duration was 3.7 seconds. This produced a skin temperature at the knee of 104° F while bare forehead skin temperature reached 126° F (52° C). As expected, rectal temperature was not changed in any experiment. This final energy level was sufficient to cause smoldering of electrical insulation within the cockpit, to char the paint on the ejection seat headrest, and to sear the brown leather flying glove on the subject's right hand. This same pulse produced a total radiant energy of 5 cal/cm^2 at the canopy outer surface, which charred paint on the fuselage. The results are summarized in Table I.

TABLE I
ENERGY-TEMPERATURE RELATIONSHIPS

Experiment Number	Total Energy cal/cm^2	Pulse Seconds	Average Energy $\text{cal/cm}^2 \text{ sec}$	Forehead T_s $^\circ \text{ F}$	$^\circ \text{ C}$
1	1.5	3.0	0.50	—	—
2	2.4	4.0	0.60	119	48.3
3	3.0	3.7	0.81	126	52.5

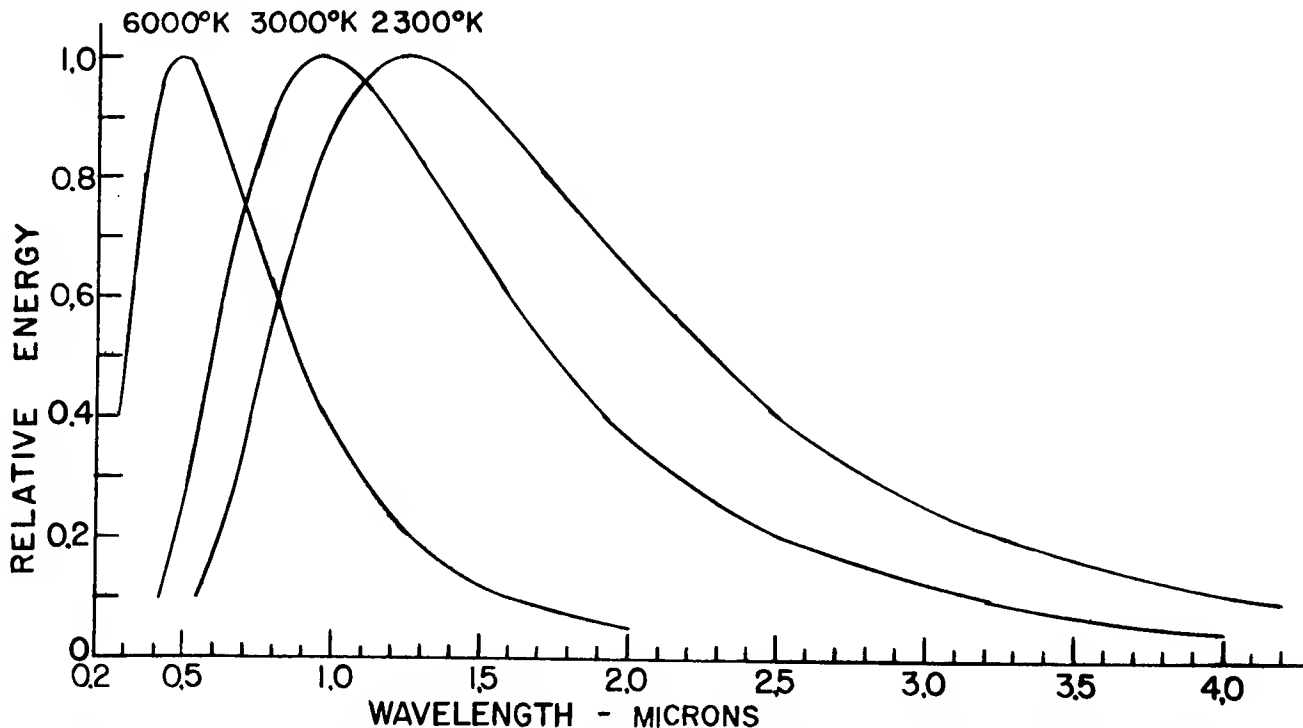


Figure 2. The Spectra of Thermonuclear Fire Ball Surfaces. Spectra are those of a black body radiating at 6000° K for an air burst, 3000° K for a ground burst and 2300° K for the laboratory simulation with radiant quartz tubes.

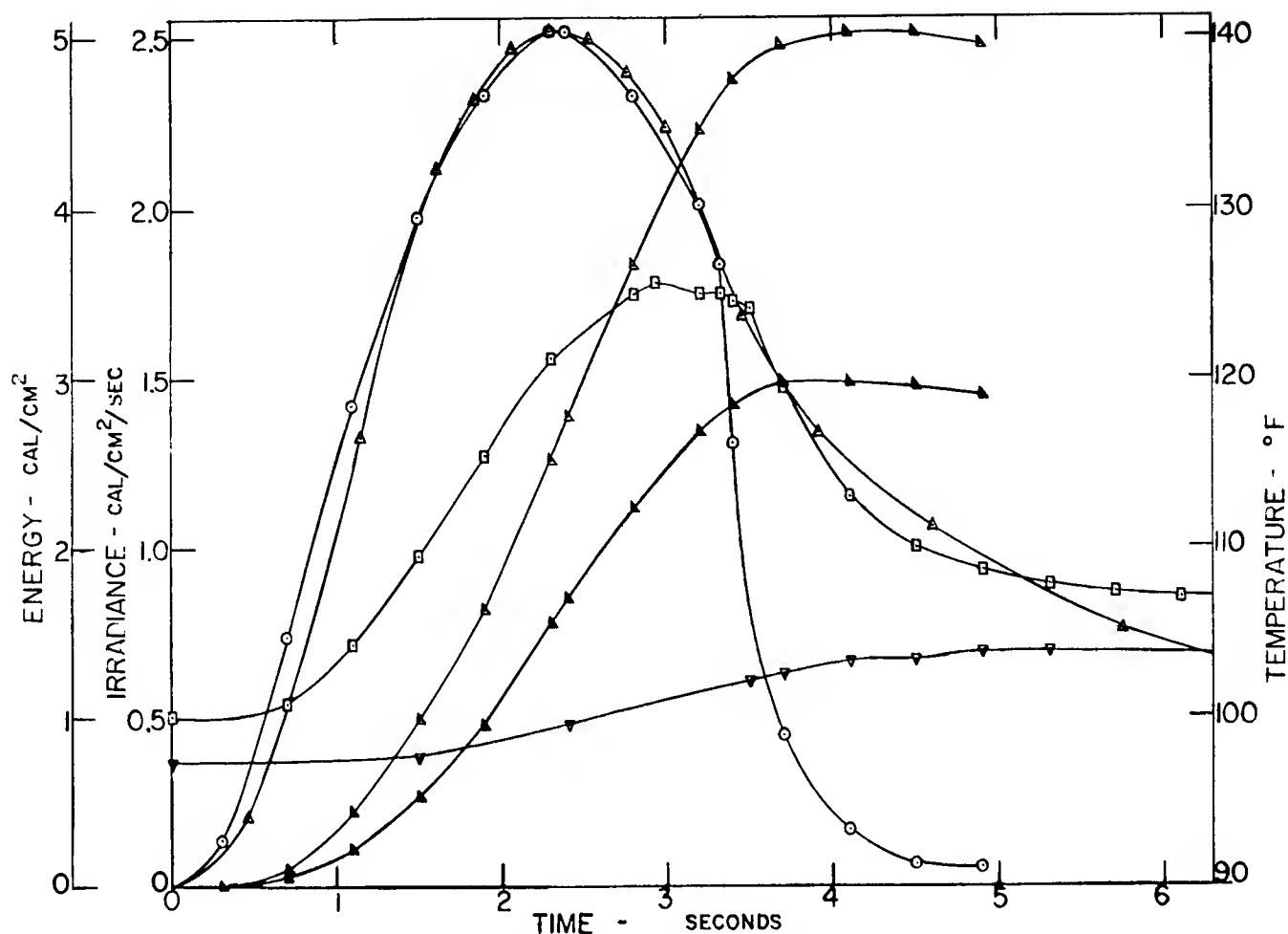


Figure 3. The Time Course of Energy from a Thermonuclear Ground Burst, Laboratory Simulation and Skin Temperatures.

- ⊙ Irradiance, laboratory: rate of change of radiant energy produced in the laboratory by quartz tubes.
- △ Irradiance, actual weapon: rate of change of radiant energy produced in a thermonuclear ground burst.
- ▢ Energy, laboratory outside: total radiant energy applied to the canopy and aircraft surface in the aircraft.
- Temperature, forehead: skin temperature of the subject's bare forehead during the experiment.
- ▽ Temperature, knee: skin temperature of the subject's knee under a summer flying suit during the experiment.
- ▲ Energy, laboratory inside: total radiant energy measured at subject's head level during the experiment.

DISCUSSION

The spectrum provided by the lamps in this experiment is a reasonable simulation of a thermonuclear ground burst (figures 2 and 3). Ionizing and ultraviolet radiation were not considered for this test since, at distances greater than one mile from the fireball, gamma radiation has little immediate effect and ultraviolet radiation is dominated by the heat effect (refs. 1, 5). The spectrum of an airburst is composed of approximately equal portions of visible and infrared radiation, but the spectrum of a ground burst at peak output is about 92 percent infrared and 8 percent visible. The laboratory quartz tubes produced a spectrum that changed as the power varied, but at peak power was 98 percent infrared and 2 percent visible.

Measurement of skin temperatures by conventional methods employing thermocouples has received much criticism (ref. 7), but there can be no doubt the thermocouple placed on the knee of the subject in this study sensed a temperature very close to that which occurred at the point where the flight suit touched the skin. However, the temperature registered by the thermocouple placed on the forehead can be questioned. The dark surface of the exposed thermocouple might very well have produced an artifact through absorption of radiant energy and 52° C is well above the temperature (45° C) generally accepted as the pain threshold. Bare forehead skin temperature was also higher than the value (48.6° C) reported as the pain threshold in applied situations (ref. 9). Although the subject described the flash as distinctly painful and his forehead became erythematous, no blistering occurred.

Experiments determining the relationship of pain threshold and skin temperature are generally performed at a constant level of irradiance (refs. 3, 11, 12). In the present experiment irradiance changed continually (figure 3) but a crude comparison to published data may be made by averaging total radiant energy over the time period. At head level this value for the final experiment was 0.81 cal/cm² sec (table I). As an indication of the severity of this level of irradiance Buettner has reported a skin temperature of 60.4° C at the end of 2 seconds of exposure to 1 cal/cm² sec and the data of Stoll and Greene (ref. 11) indicate 3-4 seconds is required to cause skin burns at this level of irradiance. During the final experiment, smoke filled the cockpit and the brightness of the flash caused the subject to release the "dead man's switch" inadvertently, breaking the circuit to the lamps. It is possible that pain may have been ignored during the emotional stress experienced and the absence of burning need not invalidate the results because of the briefness of exposure.

The severity of the thermal radiation in this experiment is further shown by the searing that occurred on the surface of the right glove at a greater distance from the quartz tubes than the subject's head. The dark surface of the glove absorbed more energy than the lighter bare forehead skin. A surface temperature of approximately 400° F (200° C) is required to produce this result*.

These data provide basic information necessary to calculate the nearest safe distance from a thermonuclear ground blast for a crewmember without special protection. Previous studies performed in this Laboratory have defined human tolerance to prolonged, severe low intensity heat stress (ref. 4, 6). In those studies the subjects were aided by full-blown physiological heat dissipation mechanisms, i.e., circulatory and sweating responses were fully developed. Tolerance was attained when physiological responses were no longer able to maintain safe body temperatures. The tolerance of human subjects to high intensity transient thermal stress has also been described by Crocker and Waitz (ref. 4). In their experiments walls of a small chamber were heated to 400° F at a rate of 100° F per minute and then allowed to cool convectively. Tolerance attained in those experiments was due to acute pain. Physiological heat dissipating mechanisms did not aid the subject greatly, since they did not develop fully until after the peak stress occurred.

In the present study thermal stress was intense, but duration of the stress was so short that the subject responded in a purely physical manner as would an inanimate object. No time was available for the subject's thermal protective responses to develop and tolerance was determined by acute pain. Comparison of results with published data indicated exposure to energy levels of greater in-

*Personal communication: L. G. Picklesimer, Fibrous Materials Branch, Non-Metallic Materials Laboratory, ASD, WPAFB.

intensity would have resulted in intense pain and probably simultaneous skin burns. Further experimentation is planned to assess the value of protective shields and methods of physiological protection (ref. 13), such as precooling, that have proved effective during longer exposures to thermal stress of lower intensity.

The data presented here establish a conservative safe limit for exposure of both aircraft and the crewmember without special protection. Radiant energy of $5.0/\text{cm}^2$ at the surface of the aircraft delivered in a pulse of 3 seconds duration is sufficient to char painted markings, $3.0 \text{ cal}/\text{cm}^2$ in a pulse of 3.5 seconds duration applied to bare skin surfaces causes distinct pain and results in skin temperatures known to be sufficient to cause tissue injury if maintained for slightly longer periods. Residual structural heat from the airframe will have little physiological effect, since it will be rapidly dissipated to the airstream.

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